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NEURAL NETWORK AND SPATIAL INTERACTION ANALYSIS OF EUROPEAN COMMODITY FLOWS

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Abstract: The present paper aims to analyse inter-regional freight transport movements in Europe in order to forecast spatio-temporal patterns of new transport economic scenarios.
In view of the high dimension of our data-base on transport flows, two different approaches are compared, viz. the logit model and the neural network model. Logit models are well-known in the literature; however, applications of logit analysis to large samples are more rare. Neural networks are nowadays receiving a considerable attention as a new approach that is able to capture major patterns of flows, on the basis of fuzzy and incomplete information. In this context an assessment of this method on the basis of a large amount of data is an interesting research endeavour.
The paper will essentially deal with a research experiment, oriented towards both calibration/learning procedures and forecasting, in order to compare the two above methodologies as well as to investigate the potential/limitations of the two above mentioned different, but related assessment methods. The first results in this framework highlight the fact that the two models adopted, although methodologically different, are both able to provide a reasonable spatial mapping of the inter-regional transport flows under consideration.

Keywords: Neural network models - Mode analysis - European networks - Forecasts - Complex systems - Computer experiments

1. A NEW SCENE FOR SPATIAL DEVELOPMENT IN EUROPE

Crossing Europe means crossing a border. The EU itself has already approximately 10.000 Km of land frontier, 60 percent of which consists of internal borders between EU members. Border regions located at two sides of the frontier between nation states have often big differences in language, culture and socio-economic conditions. Border regions are often a typical example of peripheral regions which are hampered in their development by their isolated location. Such frontier regions had usually only an orientation towards the central areas of a country and ignored their back-to-back neighbours. In the document of the European commission on "Europe 2000: Outlook for the Development of the Community's Territory" (1991) the position of border areas is phrased as follows: *"Changing borders have been a feature of Europe's political history, but most of the borders of the community have been in place for a century or more. Their experience has shaped the economic, social and cultural development of border regions and cities for even longer than that"* (p. 169). After the completion of the single European Market the frontier obstacles will mainly be removed, so that by then the border areas will assume a new position in the EU, as they represent both a potential impediment to and a potential model for the integrated development of the economic and physical space of the European territory. In the latter case new 'transborder' regions may emerge with a strong growth potential, given their transfrontier contact orientation.

Economic development takes place in a force field of competitive regions , geographical accessibility and growth bottlenecks. The European integration has meant a radical attack on many man-made borders, but bottlenecks of all kind still remain. To date, many political borders have disappeared or changed in character, exemplified by the unification of Western Europe and the opening up of the Eastern European power block. At the same time, Eastern Europe is going through a painful process of economic transformation, causing seriously high levels of unemployment. Whether vanishing political borders will lead toward more openness and economic benefits for both Western and Eastern Europe, remains thus to be seen. Mankind seems to be keen in inventing new bottlenecks precluding a free movement of people, goods and information. In addition, the heritage of political borders in terms of cultural and institutional differences may remain for a long time and prevent transborder cooperation and integration.

In contrast to earlier interregional competition based on resource availability, we observe nowadays new modes of competition based on human capital, R & D and innovative capabilities. Foreign direct investment (FDI) is investment in majority or partially owned subsidiaries, to be achieved by means of acquisition or 'greenfield' investment. Recently, the attraction of FDI has become the preferred solution of many governments in Eastern Europe for the improvement of socio-economic conditions. Foreign capital acts as a catalyst for various new developments. It is barely needed in the process of privatization as a major source of alternative finance in the absence of sufficiently large domestic savings. It is also expected to help the creation of new employment (although the initial effect is often the contray).In addition, FDI is considered as a way to enhance the introduction of innovative products, new production processes, and management skills, thereby increasing the competitiveness of industries and generating new domestic and foreign markets.

Vanishing borders also mean the opening of regional economies to many new social and economic influences, introducing particularly an increased competition between regions in view of economic power. A strong competition between regions creating win-lose situations, implies the increase of regional disparities in employment levels and welfare. High levels of unemployment are apparent in all large cities in Western and Eastern Europe, but it is particularly evident in countries facing an economic transformation which causes specific industries to close down. The latter process is not sufficiently compensated by new activities, so that there is a net loss of jobs. Unemployment affects particularly young people (< 35 years), witness for example, their share of almost 70% in the unemployed.

At the heart of much concern lies the potential emergence of a 'Golden Curtain' dividing Europe between the rich West and the poor East. Such a division (or fragmentation) would leave the East in social unrest and political instability, thereby also creating potential dangers for the West, such as from massive immigration. As a consequence, shaping the relationships between Western and Eastern Europe in a way that contributes to an integration for the benefit of both parts of Europe will be one of the most intriguing challanges of the next coming years.

It has become evident that in Western Europe R & D is strongly concentrated in a few 'island' in each country, whereas the research laboratories and enterprises in these few 'islands' work intensively together in highly exclusive networks. Due to a long history of separation, Eastern Europe is not very well linked up to these R & D 'islands'. What makes this situation worse nowadays is that severe financial stringencies prevent Eastern European scholars from participating in international research networks, leading to a persistent isolation.

Accessibility and receptivity for science and technology are important conditions in the economic powerplay between European city regions (see also Rggiani, 1998). There may be a strong competition, leading to winners and losers, and concomitant subordination relationshps and fragmentation. But there may also be a network-led cooperatin (eventually based on specialization) leading to a joint growth and integration. Networking is thus a critical competitive force, even though various impediments do exist in reality. Therefore, our attention will focus on network flows of trade in Europe, within a spatial interaction framework for the European scene.

2. CHANGES IN THE EUROPEAN FREIGHT TRANSPORT SCENE

After the completion of the European market and with the widening of Europe towards easterly direction, mobility in general has drastically increased in Europe. In particular, cross-border transport has been at a rising edge with annual growth rates exceeding 10 percent, a process reinforced by the current globalisation trends. The integration of former segmented markets -and the related liberalisation in the European space- has led to drastic changes in both goods and passenger transport.

The European Commission has recognised this restructuring phenomenon already several years ago, an observation which can also be found in the Maastricht Treaty. European networks are seen as the backbone of integration forces, while changes in the morphology of the networks are expected to generate system-wide impacts. Clearly, the emphasis on the potential of these networks for competitiveness and cohesion provokes various questions on the relative efficiency and substitutability of the different modes of this network. This issue is particularly important, as the competition between diierent modes and the social acceptability of modal choices are not only determined by the direct operational costs, but also by environmental externalities.

As a result, there is an increasing interest in the issue of intermodal competition and complementarity. For surface transport in Europe, especially the competitive position of rail vis-à-vis road is at stake. This holds increasingly also for commodity transport. It needs to be added however, that the analysis of freight transport in Europe is fraught with many difficulties, as freight is not a homogeneous commodity, but is composed of an extremely diversified set of goods with specific haulage requirements and logistic needs, This means that a commodity sector approach is necessary to analyse in depth implications of changes in network configurations. This approach will also be adopted in the present paper.

The aim of the present paper is to investigate freight flow patterns in Europe from a multiregional perspective, by looking into the modal choice for these goods essentially from the viewpoint of freight costs' In this context, two competing models, viz. a discrete choice model and a neural network model, wil be employed to map out the spatial flow patterns in an explanatory context. This offers also a possibility to compare the relative performance of those models. A selection of Dutch regions will be used to test the predictive power of the models concerned. Next, a sensitivity analysis will be carried out in order to investigate the expected consequences of a rise in transport costs, e.g. as a consequence of a European environmental tax on freight costs.

3. THE MODELS USED

The present section aims to analyse interregional freight transport movements in Europe (108 regions) as well as to forecast resulting spatio-temporal flow patterns on the basis of new transport economic scenarios. For this purpose, a modal split analysis will be carried out by means of two statistical models, namely the logit model and the neural network model.

3.1 The logit approach

A widely adopted approach for modal split analysis is the logit model (see e.g. Ben-Akiva and Lerman, 1985). Recent experiments using logit models / spatial interaction models in order to map out the freight transport in Europe have been carried out by Tavasszy(1996), who showed the suitability of logit models also for the good transport sector (where data are more 'fuzzy' and incomplete compared to the passenger sector). Logit models are discrete choice models, which are used for modeling a choice from a set of mutually exclusive and exhaustive alternatives. It is assumed that the decision-maker chooses the alternative with the highest utility among the set of alternatives. The utility of an alternative is determined by a utility function, which consists of independent attributes of the alternative concerned and the relevant parameters.

Since in our case two discrete choices - rail and road - will be considered, a binary logit model is adopted by considering, as attributes, the variables 'distance', 'time' and 'cost' between the 108 zones.

3.2 The neural network approach

Neural network (NN) analysis has in recent years become a popular analysis tool. NNs replicates human brain functions and are thus considered as 'intelligent', since they learn and generalize by examples (see e.g. Reggiani *et al.,* 1997). NNs have been widely applied to the area of transport engineering, in particular in relation to traffic control problems and accidents (see Himanen *et al.,* 1997). However, only a few

[1] The subsequent sections are based on Reggiani et al. (1998).

experiments exists in the field of transport economics or transport route / mode / destination choice (see e.g. Nijkamp *et al.*, 1996a,b and Schintler and Olurotimi, 1997). Our experiments aim to explore also this novel research direction.

Following the majority of applications on NNs, in this study a two-layer feedforward, totally connected NN will be used in order to analyse the freight transport modal split problem (see Figure 1). The methodological structure of the main steps related to the application of a feedforward NN is described in Reggiani and Tritapepe (1997). Concisely, it consists of three stages: a) definition of network architecture; b) learning phase; c) forecasting phase. It is necessary to define the right architecture of the network, i.e. the number of units on the relevant levels. Usually, the input and output units depend on the number of input and output variables which define the problem. In our application one possible NN architecture contains 4 input units which correspond to the attributes time and cost related to each transport mode (rail and road) and one output unit corresponding to the probability of choosing one mode[2] (e.g., the road mode). In the past years we have witnessed an increasing acceptance of NN models in social science research, including transportation science. Section 4 will offer empirical results obtained by applying an NN model to European freight flow data with particular attention to sensitivity/forecast analyses based on policy scenarios.

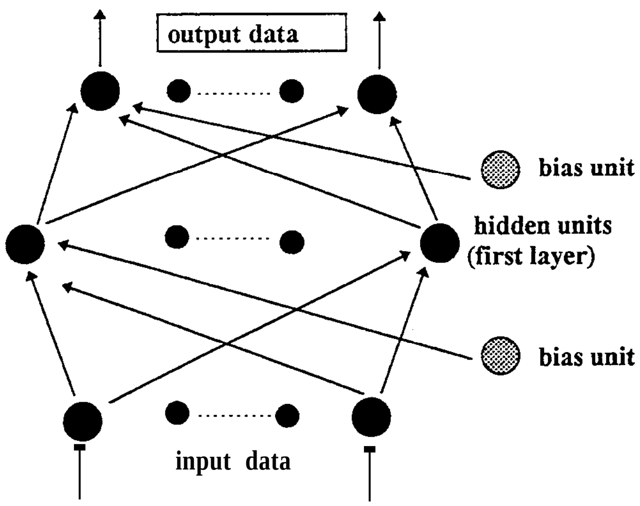

Fig. 1 A feedforward neural network architecture

[2] The choice probability of the other mode is just the complement.

4. EMPIRICAL APPLICATION

In this section the sensitivity analysis resulting from experiments with the logit and the neural network approach will be presented and discussed.

4.1 The Data

The data set[3] contains the freight flows and the attributes related to each link between 108 European regions[4] for the year 1986. The attributes considered are *'distance'*, *'time'* and *'cost'* between each link (ij) with reference to each transport mode. In particular, each observation of the data set pertains to variables related to each link (ij). Furthermore, the flow distribution in the matrices concerned refers to one particular kind of goods, viz. food.

Since 108 areas have been considered, the data set should ideally contain 11664 observations (according to the previous remarks on our observations). However, our data set contains finally 4409 observations because of the following considerations (by analysing the data set):

- the intra-area freight flows are zero;
- for each link, only the transport movements towards one direction i $\rightarrow$ j have been considered;
- only the links where the flows and the attributes (of both road and rail) are different from zero have been considered (i.e., empty cells are excluded).

The data set has been randomly subdivided into three sub-sets:

- a *training set* containing 2992 observations, i.e. about 68% of the data-set;
- a *cross-validation set* containing 447 observations, i.e. about 10% of the data-set;
- a *test set* containing 970 observations, i.e. about 22% of the data-set.

4.2 The spatial forecasting: comparison of the logit and neural network approach

In this subsection, the spatial forecasting performance of the two alternative approaches adopted will be compared and evaluated, on the basis of the calibration/learning procedure carried *out* in Reggiani *et al.*(1998).

By using the test set, which was not used for the calibration procedure, in our procedure both the binary logit and the neural network model have been employed to predict the freight flows for link (ij). This performance has been evaluated using the statistical indicator ARV (Average Relative Variance) which reads as follows:

$$ARV = \frac{\sum (y - \hat{y})^2}{\sum (y - \bar{y})^2} \qquad (1)$$

[3] The data set has been kindly provided by NEA Transport Research and Training Rijswijk
[4] The map and list of regions is displayed in Reggiani *et al.* (1998).

where y = the observed transport flow using the road mode, $\hat{y}$ = the transport flow using the road mode, predicted by the adopted model, and $\bar{y}$ = the average of the observed transport flow using the road mode (see Fischer and Gopal, 1994).

Table 1. Comparison of Logit and NN performance

	ARV
NN	0.176
Logit	0.185

According to the above ARV indicator, the NN approach for forecasting spatial flows performs overall slightly better than the logit approach (see Table 1). An extrapolation of the 'test-set' results with reference to 3 Dutch regions (inflows to Europe/outflows from Europe) is displayed in Table 2 and 3 (see next section).

4.3. Policy scenario experiments by means of Iogit and neural network analyses

As mentioned above, freight transport causes high social costs, which might be charged to the transportation sector. We will now investigate the consequences of varying the transportation costs for freight flows. A sensitivity analysis of the previous results based on some economic scenarios will now be carried out in this section by using again both the binary logit model and the NN model. Two economic scenarios will be used; they will concisely be discussed here. Later on, we will present the results related to the sensitivity analysis for the logit and the neural network approach.

At present, because of severe problems on the road transport network (for example, congestion), governments are trying to reduce the road usage by imposing policy measures that serve to increase the cost of road usage (see Verhoef, 1996). An example of a Pigouvian policy for coping with environmental externalities is the recently increased tax on fuel in the Netherlands. In so doing, the usage of the road transport network is made less attractive than other transport networks. In the light of these recent developments, two scenarios have been developed and considered for an sensitivity analysis; these are based on the observations in the test set. In Scenario 1 we assume that a uniform European tax policy for freight transport is adopted and that the cost attribute related to the road mode is increased by 25 % for all links (ij). Scenario 2 assumes only a national environmental policy, which means that same cost increase is made exclusively for links (ij) which start or end in Dutch regions.
The conditional predictions for the three Dutch regions are presented in Tables 2 and 3 for the binary logit and the neural network model, respectively. The relative prediction error (see Tables 2 and 3) is defined as the difference between the predicted flow and the real flow as a percentage of the real flow. These tables indicate that the binary logit model is relatively more sensitive to changes in the cost attribute than the NN model. Table 2 also shows that the binary logit model gives the same predictions in the two scenarios, which is caused by the independence of irrelevant alternatives feature (IIA) of this discrete choice model. The NN model estimates appear to give the lowest prediction error.

It is interesting to note that in the neural network **case,** and particularly in the case of inflows from Europe to the Netherlands, the model shows -in the mean value- an increase of flows, despite the cost increase.

This result may be plausible by taking into account the increasing amount of interaction among regional flows. It would certainly be relevant to compare these results with more updated data in order to better evaluate the 'forecasting' analysis of the two models, since we have used -as a starting point- a test set related to the year 1986.
However, the above results may be considered valid, in the absence of updated data that would be able to test our hypothesis of a 25% increase in the costs, given the good performance of the calibration / test phase (see table 1). Moreover, these results may offer a 'range of values' to policy actors aiming to evaluate the impact of cost changes on flows, given the intrinsic limits of both adopted models.

On the one hand, the large amount of data at an aggregate level, hampers a behavioural perspective inherent in logit models. On the other hand, the type of architecture adopted in NN models seems critical for the validity of the results. Consequently, the results of our model may be used as a benchmark for the results of other models, by offering a more 'flexible'output to policy actors.

Table 2 Results of the sensitivity analysis for the binary logit model (columns b and c)

	Food Transport Flows				**Relative Prediction Error**		
From NL to Europe	*real flow*	*pred. flow*					
Regions		**a) test set**	**b) scen. 1**	**c) scen. 2**	**a)**	**b)**	**c)**
Breda	181032	170981	161327	161327	-5,6%	-10,9%	-10,9%
Eindhoven	968534	904321	861082	861082	-6,6%	-11,1%	-11,1%
Maastricht	264424	252429	245336	245336	-4,5%	-7,2%	-7,2%
TOTAL	1413990	1327732	1267745	1267745	-6,1%	-10,3%	-10,3%
From Europe to NL	*real flow*	*pred. flow*					
Regions		**a) test set**	**b) scen. 1**	**c) scen. 2**	**a)**	**b)**	**c)**
Breda	15922	15837	15599	15599	-0,5%	-2,0%	-2,0%
Eindhoven	119772	121918	119056	119056	1,8%	-0,6%	-0,6%
Maastricht	59880	59550	58363	58363	-0,6%	-2,5%	-2,5%
TOTAL	195574	197304	193018	193019	0,9%	-1,3%	-1,3%

Table 3 Results of the sensitivity analvsis for the neural network model (columns b and c)

	Food Transport Flows				Relative Prediction Error		
From NL to Europe	*real flow*	*pred. flow*					
Regions		**a) test set**	**b) scen. 1**	**c) scen. 2**	**a)**	**b)**	**c)**
Breda	181032	176781	175783	171600	-2,3%	-2,9%	-5,2%
Eindhoven	968534	945732	941847	930447	-2,4%	-2,8%	-3,9%
Maastricht	264424	255930	255261	254181	-3,2%	-3,5%	-3,9%
TOTAL	1413990	1378442	1372891	1356228	-2,5%	-2,9%	-4,1%

From Europe to NL	*real flow*	*pred. flow*					
Regions		**a) test set**	**b) scen. 1**	**c) scen. 2**	**a)**	**b)**	**c)**
Breda	15922	15634	15598	15508	-1,8%	-2,0%	-2,6%
Eindhoven	119772	122434	122117	121270	2,2%	2,0%	1,3%
Maastricht	59880	60010	59832	59368	0,2%	-0,1%	-0,9%
TOTAL	195574	198077	197548	196146	1,3%	1,0%	0,3%

5. CONCLUDING REMARKS

This paper has aimed to depict transport flows of commodities in an inter-regional European setting. Based on an extensive (NEA) data set, various estimates of the impacts of costs on transport movements have been made. The test results show that both the logit and the NN approach are giving fairly favourable results. In general, NN models seem to perform slightly better. After this exploratory comparative study of two modelling approaches, it is certainly opportune to investigate more thoroughly the differences in background of these two research paradigms. It is well known that the logit model is a particular spatial interaction model that has its roots in social behaviour of actors, however with the limit of assuming certain properties, like the well known IIA (Independence from Irrelevant Alternatives) assumption. The NN model is based on similarily of learning experiments and has certainly a behavioural adjustment potential, but is less easily interpretable from social science motives, even though recent results show a compatibility between feedforward NNs and binary logit models (see Schintler and Olurotimi, 1997), feedforward NNs and spatial interaction models (see Fischer and Gopal, 1994) and feedforward NNs and logistic regression models (see Schumacher et al., 1996). Given its predictive ability, more research is needed to better investigate the behavioural roots of NN models.

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